Development of a Vegetation Map for the Catskill Mountains, NY, Using Multi-temporal Landsat Imagery

Final Report

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USDA Forest Service, Northeastern Research Station

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1.0 Introduction

The largely forested Catskill Mountains of southeastern New York are regarded as subject to high rates of atmospheric deposition of pollutants and nutrients due to their proximity to New York City and surrounding urban areas (Weathers et al. 2000). The Catskills also provide 90% of the water supply for New York City (New York City Department of Environmental Protection [NYCDEP] 1993). These circumstances, along with basic biogeochemical questions, have generated considerable research into nutrient cycling in the Catskills in particular (e.g., Lovett and Rueth 1999, Lawrence et al. 2000, Weathers et al. 2000, Lovett et al. 2000) and the northeastern US in general (e.g., Ollinger et al. 1993).

Vegetation, particularly the distribution of tree species and the interaction of vegetation and topographic position, can strongly influence nutrient deposition rates (Weathers et al. 2000). Additionally, species composition affects nutrient cycling after deposition has occurred (Lovett and Rueth 1999). To more fully understand these factors across geographic space in the Catskills requires a vegetation map that: 1) emphasizes the distribution of tree species, 2) is highly resolved in terms of individual tree species dominance, and 3) has sufficient spatial resolution to capture the fine-grained character of vegetation in this region. The general objective of the project described here was to provide such a map, using Landsat Thematic Mapper (TM) satellite imagery and other digital data. This report describes the methods used to create this map, the characteristics of the resulting classification, the results of a preliminary ground-based accuracy assessment of the map, and recommendations for improving the map in the future.

2.0 Methods

2.1 Digital Data Acquisition

To take advantage of phenological differences between deciduous tree species, we acquired Landsat TM data from the Catskills for four scene dates capturing pre-green-up, green-up (spring), summer leaf-on, and fall color change. Ideally, satellite data for multi-temporal classification is acquired from a single year, with acquisitions linked to field observation of species-specific phenological change. This was not possible for this project because of a lack of cloud-free imagery for some target dates, and because of the high cost of some satellite "scenes". Within these constraints, we purchased Landsat TM data (Path/Row = 14/31) for dates capturing the widest possible range of phenological change (Table 2.1).

Table 2.1. Landsat Thematic Mapper (TM) data acquired for Catskills mapping. Scene ID is the USGS entity ID. Acquisition data is the date that the scene was collected by the Landsat satellite. Scene source is the agency from which each scene was purchased (MRLC = Multiple Resolution Land Characterization Program). Phenological stage is based on field notes from the Catskills during 1998 and 1999.

Scene ID	Acquisition Date	Scene Source	Phenological Stage
MGM0140310428198900	28 April 1989	USGS/MRLC Program	Leaf off (pre-green-up)
MGT0140310509199300	9 May 1993	USGS/MRLC Program	Low elevation green-up
MGM0140310621199100	21 June 1991	USGS/MRLC Program	Full leaf on
LT5014031008630210	29 Oct 1986	USGS/EROS Data Center	Oak leaf on, other species leaf off.

These data are centered on approximately N 41º45'41" W 74º27'08" (there is small variation from one date to another) and are cloud free, with the exception of the 9 May scene, which included a few clouds in the southeast corner of the study area, and the 21 June scene, which had some high clouds in the northeastern portion of the study area. Data cover an area extending from approximately Wilkes-Barre, PA in the southwest, to Yonkers, NY in the southeast and from Pittsfield, MA in the northeast to Sherburne, NY in the northwest (approximate scene corners). All data were geographically and terrain corrected by the USGS and projected into UTM Zone 18 (units = meters; spheroid = GRS1980, datum = NAD1983). Spatial resolution is 30 m. TM data include 6 reflected spectral bands and an emitted thermal band. The thermal band was not used for mapping in this project.

Digital elevation models (DEMs) were provided by the USGS with each TM scene from the Multi Resolution Land Characterization (MRLC) Program. These DEMs are registered to the satellite data and are of the same spatial resolution (30 m). DEM data were used in the classification, especially to help separate conifer species (Figure 2.4).

2.2 Ground Data Acquisition

Species composition data were collected in the Catskills by IES staff during the summers of 1999 and 2000. These data were a basis for generating "training sites" used for supervised classification of satellite imagery. Ground data were also collected by IES in 2001 for additional training data and for map accuracy assessment, and were supplemented by data collected by the New York City Department of Environmental Protection on their property in the Catskills. Accuracy assessment data were *not* used for classification to maintain the statistical independence of the accuracy assessment.

Ground data were collected at 249 sites, located along roads and trails in the Catskills to avoid the difficulties of accessing more remote areas. This was a compromise between statistical rigor and practical necessity, an unavoidable tradeoff resulting from time and budget constraints (see Stehman [2001] for a discussion of tradeoffs in accuracy assessment). Although not especially problematic for training data, lack of a geographically distributed, random sample of sites did adversely affect our ability to make inferences based on the accuracy assessment (Stehman 2001) (Sections 2.5, 3.2).

Site data for training and accuracy assessment included the coordinates (collected using a GPS in the field) of the intersection of the corners of four, 50-meter PRISM plots (Figure 2.1). Data from these plots were summarized and provided to Driese in the form of spreadsheets (Microsoft Excel) listing the collective basal area of each tree species encountered at each site. Of the 249 total sites visited on the ground, 135 were used for training data and 114 were set aside for accuracy assessment (Table 2.2, Figs, 2.2, 2.3).

PRISM PLOT SAMPLING

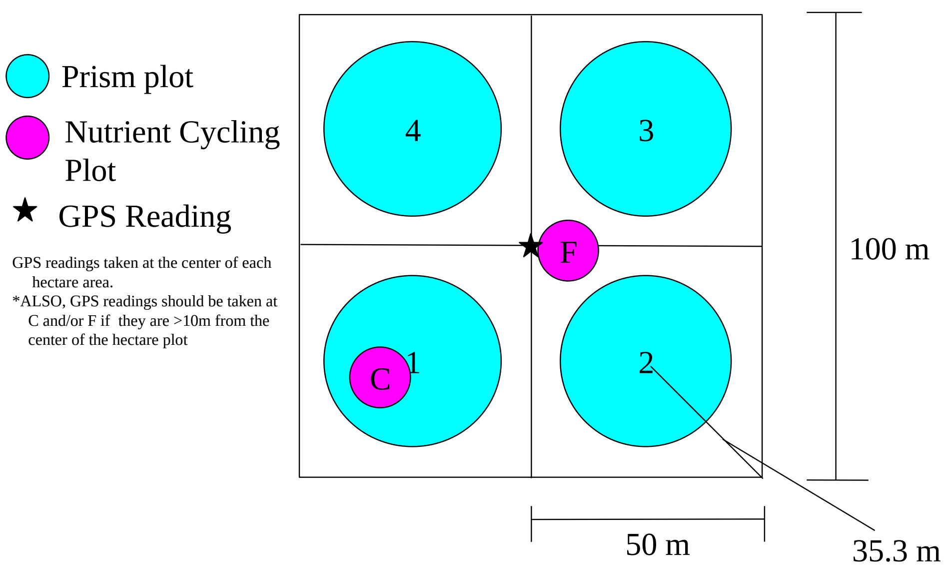

Figure 2.1. Schematic showing the sampling configuration used on the ground for collecting species data for training and accuracy assessment data.

Site data were further summarized by lumping similar species (Appendix A). For example, the proportional cover of maple at a site was calculated by summing the basal area of all maple species (e.g., sugar maple, red maple, striped maple) and dividing by the total basal area of all species at that site. This facilitated matching of ground data to the classification scheme (Section 2.3 below) for both training and accuracy assessment. The total number of accuracy assessment sites for each type in the classification scheme are presented in Table 2.2 and the map locations of the training and accuracy assessment sites are shown in Figures 2.2 and 2.3, respectively. Training sites were extrapolated both from ground sampling sites and from field reconnaissance by Driese in the Catskills in 1999. Accuracy assessment sites are point locations (single pixels).

Table 2.2. The total number of accuracy assessment sites by cover type. Cover types refer to the classification scheme described in Section 2.3 and listed in Table 2.3 below.

Cover Type of Ground Data	**Number of Accuracy Assessment Sites**
1	0
2	0
3	0
4	0
5	9
6	2
7	3
8	6
9	2
10	4
11	8
12	3
13	6
14	4
15	9
16	1
17	5
18	9
19	11
20	5
21	6
22	2
24	3
25	16
Total	**114**

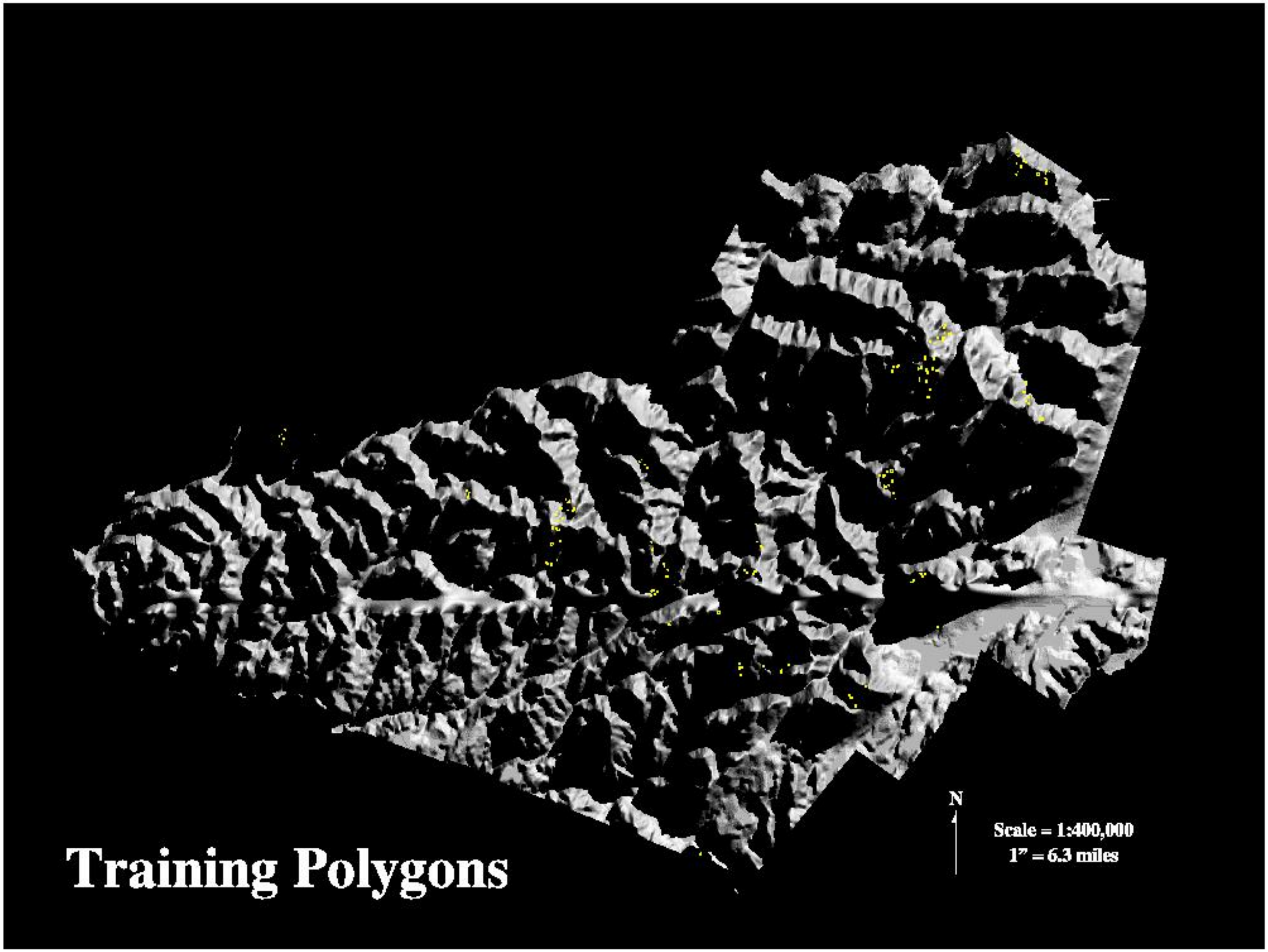

Figure 2.2. Locations of the training polygons (in yellow) used for classifying satellite data to create the landcover

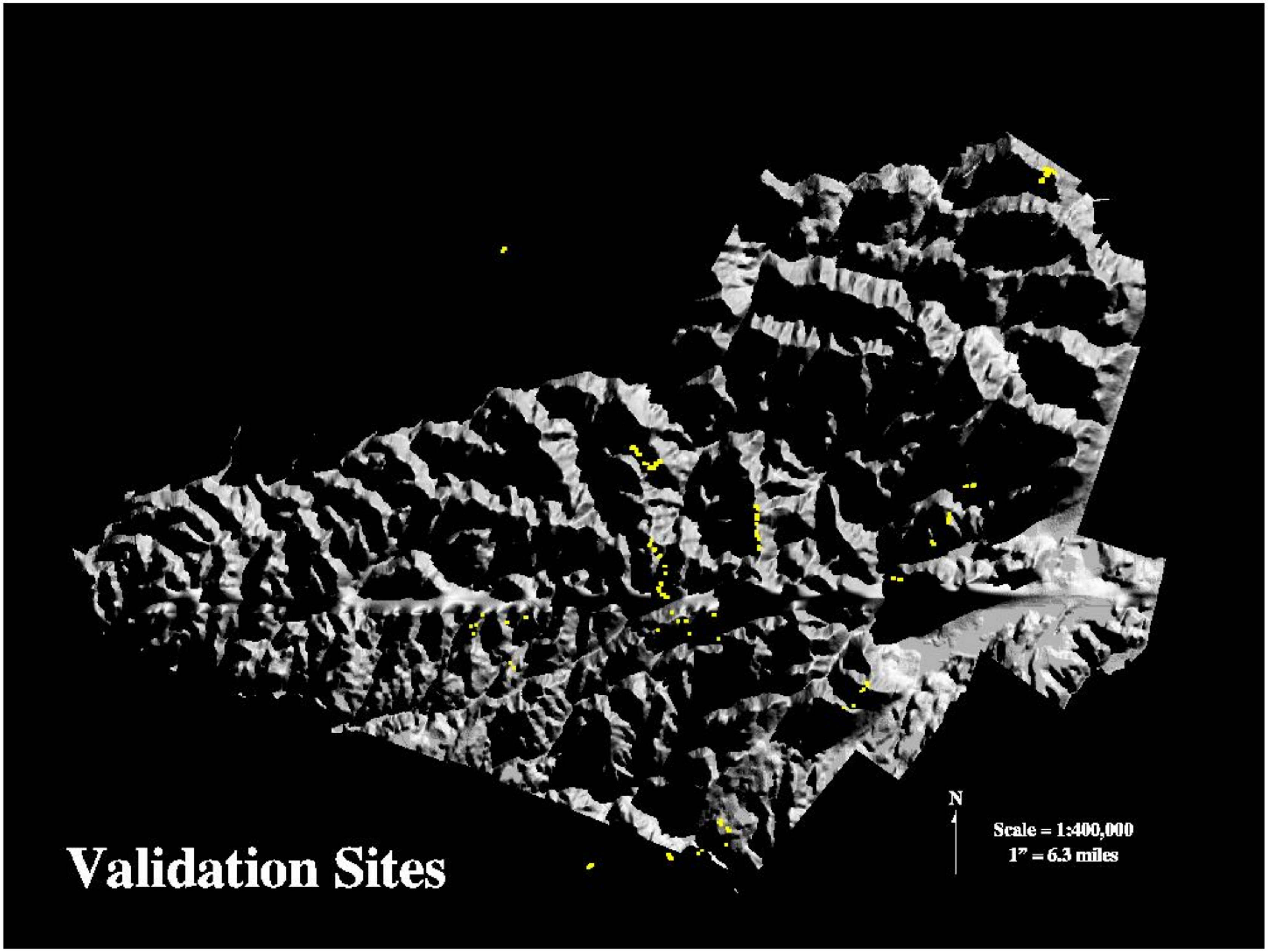

Figure 2.3. Locations of sites (in yellow) used for the accuracy assessment of the Catskills landcover map. Sites are overlayed on a shaded relief image of the area within the boundary of the Catskills Park.

2.3 Landcover Classification Scheme

The vegetation classes identified as important for biogeochemical analysis of Catskills watersheds are spruce-fir, hemlock, oak, beech, maple and an "other" class including ash, black cherry, aspen and miscellaneous tree species. Because ground data included detailed quantitative information about species basal area (Appendix A) at each training site, we developed a classification system comprised of a more detailed list of forest types (Table 2.3), as well as three non-forest classes. At the outset of the project, we anticipated lumping these detailed classes to create the final map, but because the detailed classification provides useful information it was retained. Detailed classes were especially helpful for comparison between mapped types and validation data (Section 3.2).

Table 2.3. Land cover classes in the final version of the Catskills map and/or in the field data. Map codes refer to the pixel values in the digital map. Type names include the dominant species first with other significant species following. "Dominant" and "significant" are defined in the text below.

Map Code	Type Name	Description
1	Water	Open water – Lakes, rivers, reservoirs, etc.
2	Non-forest	Grass, bare soil, etc.
3	Human built up	Roads, urban areas, etc.
4	Oak/laurel forest	Relatively pure oak dominated forest with laurel understory
5	Oak forest	Relatively pure oak dominated forest
6	Oak/maple forest	Oak dominated forest with significant maple component
7	Oak/beech or birch or "other" forest	Oak dominated forest with significant beech *or* birch component
8	Maple forest	Relatively pure maple dominated forest.
9	Maple/oak forest	Maple dominated forest with significant maple component
10	Maple/birch forest	Maple dominated forest with significant birch component
11	Maple/beech forest	Maple dominated forest with significant beech component
12	Maple/birch/beech forest	Maple dominated forest with significant birch *and* beech components
13	Maple/other forest	Maple dominated forest with significant "other" hardwoods present (e.g. ash, cherry, aspen)
14	Birch forest	Relatively pure birch dominated forest
15	Birch/maple or beech or "other" forest	Birch dominated forest with significant maple *or* beech components
16	Beech forest	Relatively pure beech dominated forest
17	Beech/maple forest	Beech dominated forest with significant maple component
18	Beech/other forest	Beech dominated forest with "other" hardwoods (e.g. ash, cherry, aspen)
19	"Other" forest	Forest dominated by deciduous species not including beech, maple, oak, and birch.
20	"Other"/maple forest	Forest dominated by "other" species with significant maple component
21	Spruce/fir forest	Forest dominated by spruce and/or fir species
22	Hemlock/pine forest	Forest dominated by hemlock and/or pine species
24	Spruce/fir/decid forest	Forest with a mixture of spruce, fir, and deciduous species.
25	Hemlock/pine/decid forest	Forest with a mixture of pine, hemlock, and deciduous species.

In this classification, a species (or species group) is considered dominant if it collectively occupies more basal area in a plot or pixel than any other species (or species group). For example, in pixels mapped as maple/beech forest (Type 11 in Table 2.3) more basal area is occupied by maple species than by other species in the pixel. Furthermore, to be considered a significant component, beech in these pixels must occupy within 25% of the proportion of total basal area of the dominant type. If maple occupies 50% of a pixel, beech must occupy at least 25% of the pixel to be included as a significant subdominant. These definitions recognize species occupying substantial portions of the total tree basal area in each map unit.

Oak forest / laurel (type 4) and oak forest (type 5) in the classification (Table 2.3) are the same in terms of dominant vegetation (relatively pure oak). We retained the two classes because they were spectrally distinguishable in the TM imagery. The oak laurel type had an unusual spectral signature in the April scene (pre-green up). We assumed this represented the evergreen laurel understory, but we did not take ground data on understory composition so this remains a "best guess." For the accuracy assessment, these two classes (4 and 5) were treated as equivalent. Birch-dominated forest, originally lumped with the "other" forest type, is separated in the classification because it is widespread and spectrally distinct. It is treated as equivalent to "other" species in the fuzzy accuracy assessment (Section 3.2.2).

2.4 Digital Classification

The Catskills map was built in stages by performing a series of digital classifications (using Erdas Imagine version 8.4, Erdas, Inc., Atlanta, GA) designed to separate particular target classes or groups of classes (Figure 2.4). This decision tree approach used TM spectral bands, transformed and enhanced TM data, elevation data, and data derived from elevation data. Each stage of the decision tree evolved from research to identify data combinations that best distinguished particular classes (Table 2.4) and many "dead ends" were encountered that are not described here. Spectral response plots for classes represented in the ground data were generated for various data enhancements. Data that accentuated spectral differences between vegetation classes were used, along with the ground-based training data, to generate a series of supervised classifications. Land cover classes from these supervised classifications were added incrementally (Figure 2.4) to an evolving draft map that eventually became the final map (Figure 3.1).

Although most of the decision tree (Figure 2.4) is self-explanatory, the branches concerning forest types (evergreen and deciduous) deserve additional discussion. Evergreen and deciduous species were initially separated from one another using a supervised maximum likelihood classification of the April green, red and near-infrared (NIR) bands from the satellite data (bands 2, 3 and 4 respectively). Data exploration for each group diverged after this, with evergreen species distinguished primarily using data derived from the DEM, and deciduous species distinguished using spectral data enhancements. The layers of refinement of evergreen classification in the decision tree were designed to "tune" the mapped locations of these types to match field experience.

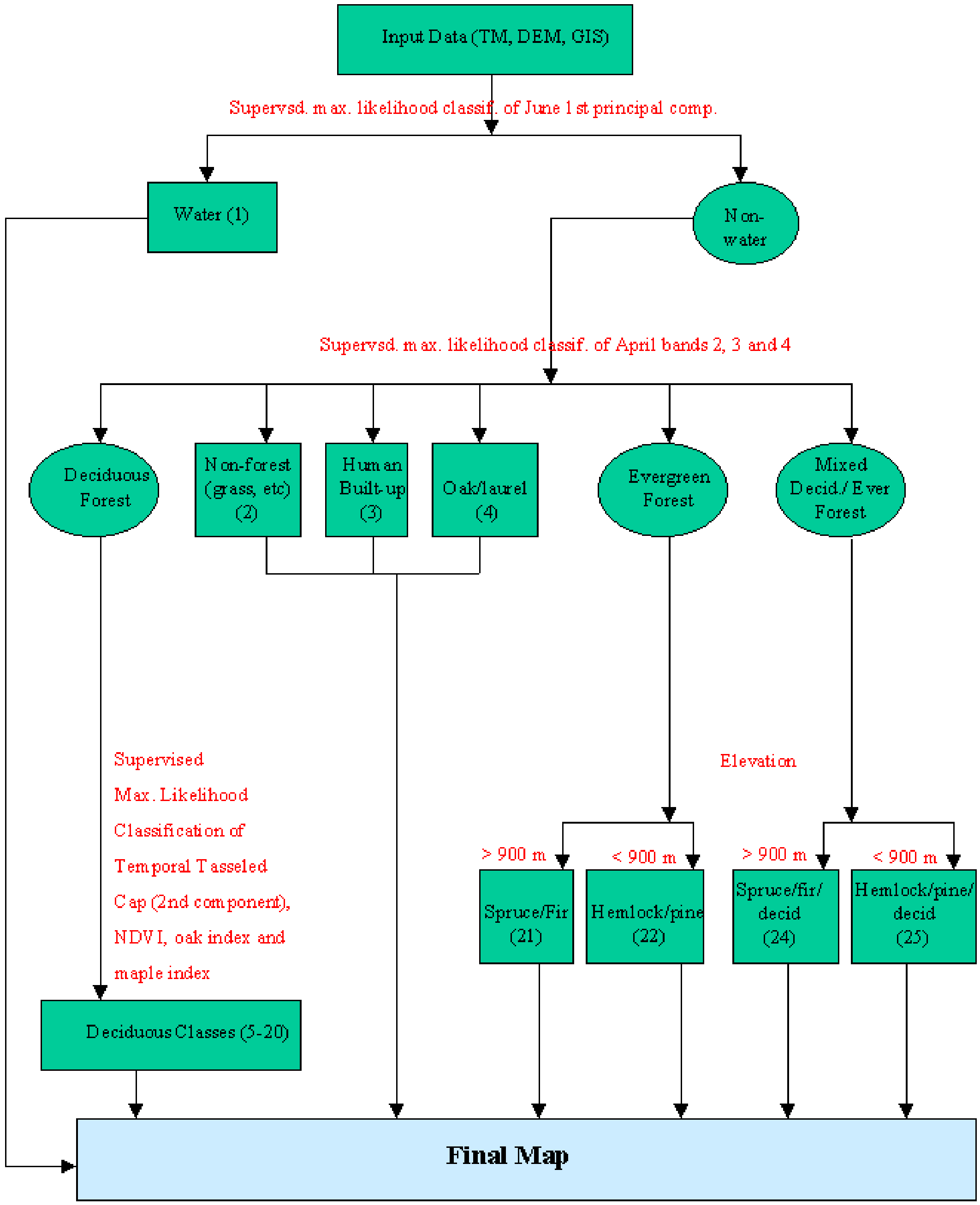

Figure 2.4. Flowchart showing the processing tree used to create the Catskills vegetation map. Processing steps and rules are in shown in red. Intermediate classes are contained within green ovals and final classes within green rectangles. See text for explanation.

Table 2.4. Digital data that were examined for their potential value for separating Catskills vegetation types with general comments. Data enhancements that were used to create the final map are noted in the "Comments" and discussed in the report text.

Digital Data Enhancement	**Comments**
TM Bands	Explored individual TM bands from each date and across dates. Bands 2, 3 and 4 from the April scene were used to separate deciduous from evergreen, non-forest and oak/laurel (Figure 2.4). Other individual bands were not used.
Normalized Difference Vegetation Index (NDVI)	NDVI was calculated for each scene date and explored for each date and multi-temporally. Multi-temporal NDVI was used (simultaneously with other enhancements) to distinguish deciduous classes (Figure 2.4).
Principal Components Analysis (PCA)	PCA was performed for each scene date using the 6 reflective bands. The first principal component (PC1) from the June scene was used to separate water from non-water (Figure 2.4).
Tasseled Cap (TC)	Kauth's Tasseled Cap transformation (Kauth and Thomas 1976) was calculated for each date.
Temporal PCA	Principal components were plotted over time using the 4 scene dates.
Temporal TC	Kauth's Tasseled Cap components were plotted across time (for the four dates) to observe temporal patterns. The temporal profile of TC2 was used (simultaneously with other enhancements) to distinguish deciduous types (Figure 2.4).
Maple Index	A "maple index" (see text) was devised to enhance the observed characteristics of the temporal reflectance of maple sites. This index was used (simultaneously with other enhancements) to distinguish deciduous types (Figure 2.4).
Oak Index	An "oak index" (see text) was devised to enhance the observed characteristics of the temporal reflectance of oak sites. This index was used (simultaneously with other enhancements) to distinguish deciduous types (Figure 2.4).
Birch Index	A "birch index" was devised to enhance the observed characteristics of the temporal reflectance of birch sites. This index was not used in the final classification.
Elevation	DEM data were used to split evergreen forest into spruce/fir and hemlock/pine (See rules in Figure 2.4).

Classification of deciduous species was the core of the project and the data used to distinguish species arose from trial and error using many combinations of spectral data. The final product resulted from a supervised maximum likelihood classification, using all of the training data, of a 10-band image consisting of four data enhancements. These enhancements included: 1) the temporal profile of the 2nd Tasseled Cap component, 2) the temporal NDVI profile, 3) an oak index and 4) a maple index. The tasseled cap transformation (Kauth and Thomas 1976) is a data reduction technique similar to principal components analysis but without the requirement of orthogonal axes. Examination of each of the six tasseled cap components suggested that the 2nd (TC2) (usually associated with vegetation greenness) would be useful for highlighting the spectral differences in deciduous species. By using the temporal profiles of this component and the NDVI, we were able to exploit phenological differences in the spectral data.

Two enhancements were developed to highlight specific aspects of the spectral response of maple and oak in the Catskills. Maple and oak indices were calculated that accentuated features of the temporal NDVI and TC2 profiles, respectively. The maple index used the formula:

$$\text{(June NDVI/May NDVI)/(May NDVI/April NDVI)}$$

Similarly, the oak index was calculated as:

$$\text{(June TC2/May TC2)/(May TC2/April TC2)}$$

Both indices were linearly stretched to match the 8-bit range of digital numbers (0-255). These indices, though not complex, helped significantly for distinguishing deciduous species in general.

The final map (Figure 3.1) is a combination of the classifications at the end of each branch of the classification tree (Figure 2.4). This approach allowed different components of the map to be separated according to different data combinations that best distinguished them.

2.5 Map Accuracy Assessment

Thematic map accuracy assessment is based on comparing particular places on a derived map (like the Catskills vegetation map) to reference data, presumed to accurately describe the “true” character of corresponding places on the ground. The patterns of matches and mismatches between a derived classification (the map) and reference data (“ground truth”) can subsequently be used to generate statistics and indices describing various aspects of map accuracy (Congalton and Green 1993). The goal of such assessments is to provide map *users* with information about the strengths and weaknesses of a particular map for particular purposes, and to provide map *producers* with information that might lead to improved classification. Map accuracy can be expressed in the context of binary scores (right vs. wrong) for each assessment site, an approach that we call “traditional accuracy assessment” (Congalton and Green 1993), or using a verbal scale (Table 2.5) defining degrees of error. The latter is called “fuzzy accuracy assessment” (Gopal and Woodcock 1994). In our opinion, fuzzy accuracy assessment provided more information in the

Catskills, where the continuous gradients in species mixtures blurs the line between "correct" and "incorrect" pixel classification. We present the results of both traditional and fuzzy assessments of the map.

Table 2.5. The verbal "correctness" scale and associated codes used for fuzzy accuracy assessment based on the work of Gopal and Woodcock (1994).

Code	Description
5	Absolutely right
4	Good answer
3	Reasonable or acceptable answer
2	Understandable, but wrong
1	Absolutely wrong

Reference data for accuracy assessment of the Catskills map were collected by IES personnel (see Section 2.2) in 2001. As described above, these data included detailed descriptions of tree species composition, quantified in terms of basal area of each species at each site. Site data included the coordinates (collected using a GPS in the field) of intersection of the corners of four, 50-meter PRISM plots (Figure 2.1). Data from these plots were summarized and provided to Driese. In total, 114 sites were used for this assessment (Table 2.2). Sites were located along roads and trails due to logistical problems with a fully random sample. The relatively small number of sites compared to the number of mapped classes and the lack of a fully random sample limit the power of the assessment described here, but we feel that the results offer useful hints at map characteristics. Reporting these results is for the purpose of guiding future efforts, but we emphasize that they should not be used as a statistically valid, quantitative assessment of the accuracy of the Catskills map. A more comprehensive and statistically rigorous assessment may be conducted in the future if funding is secured.

3.0 Results

3.1 Map Characteristics

The map domain for this project is the Catskills Park, whose boundary encloses an area of about 700,000 acres (2817 km^2). Because this is a small part of the area covered by a Landsat TM scene, we used a subset of the TM data that subsumed the entire Catskills Park boundary. Mapped areas outside the park boundary should be used with caution, since few training sites or validation data were present there. Map characteristics described in the remainder of this section refer to the area *within* the park boundary only (Figure 3.1).

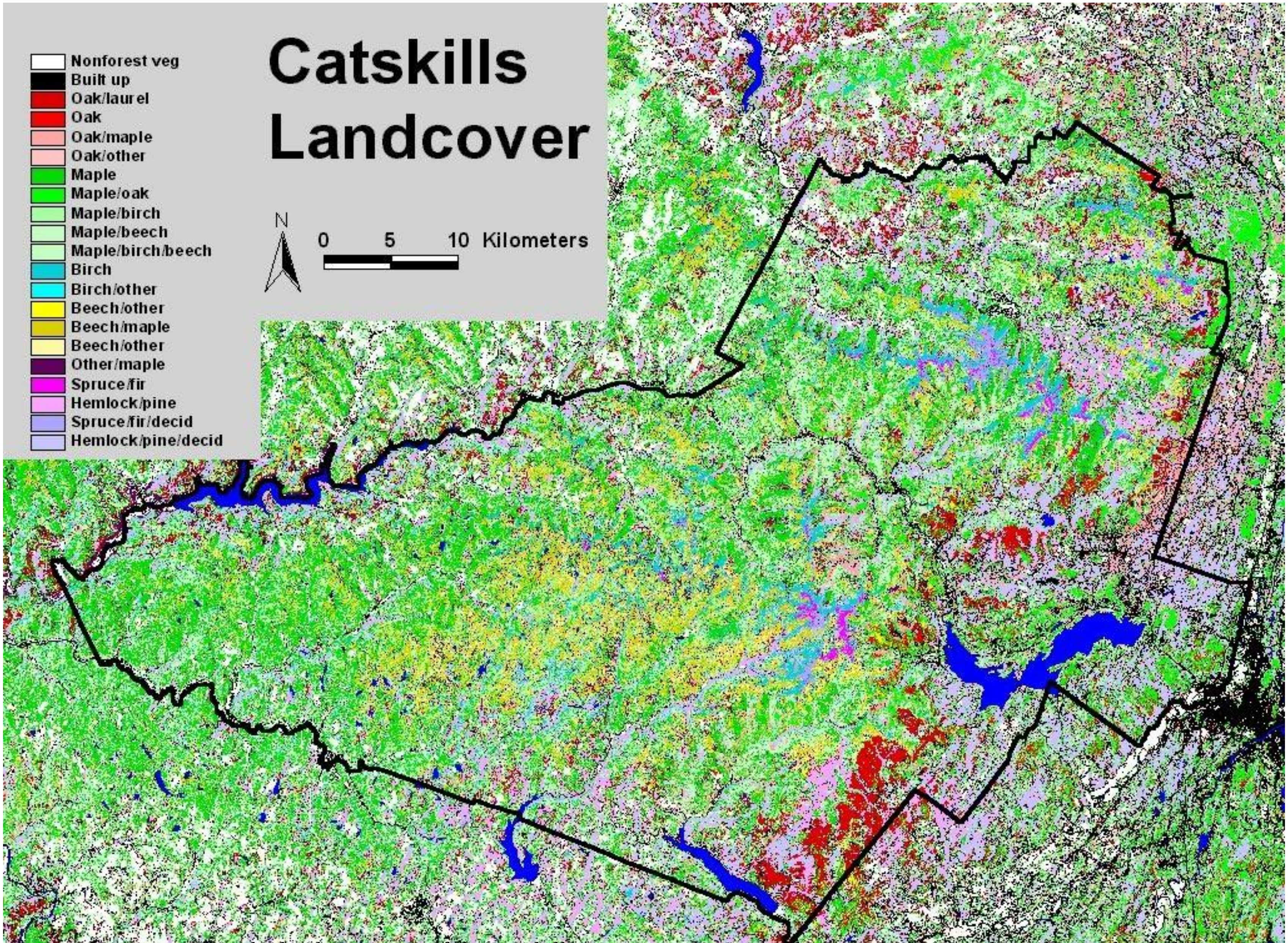

Figure 3.1: The landcover map of the Catskills. Species are grouped by genus using similar colors. The dark line indicates the boundary of the Catskills park. Corresponding digital data are provided on CD.

Catskills vegetation is dominated by deciduous tree species, although non-forest and evergreen species are a significant component of the landscape (Table 3.1). Specifically, non- forest types (including open water) collectively occupy 12.7% of the Catskills Park. Deciduous cover types occupy 71.58%. Evergreen-dominated types occur in 4.27% of the area and evergreen/deciduous mixtures cover 11.45%.

Table 3.1. Area (km^2) and proportional area (% total) occupied by each of the 24 land cover classes within the boundaries of Catskills Park. Cover codes match the grid values in the digital map.

Cover Code	Cover Type	Area (km^2)	Area (% total)
1	Water	62.88	2.23
2	Non-forest	130.23	4.62
3	Human built up	164.69	5.85
4	Oak/laurel forest	123.98	4.40
5	Oak forest	27.69	0.98
6	Oak/maple forest	103.67	3.68
7	Oak/beech or birch or “other” forest	8.69	0.31
8	Maple forest	481.10	17.08
9	Maple/oak forest	157.72	5.60
10	Maple/birch forest	85.86	3.05
11	Maple/beech forest	204.60	7.26
12	Maple/birch/beech forest	291.64	10.35
13	Maple/other forest	0.00	0.00
14	Birch forest	122.93	4.36
15	Birch/maple or beech or “other” forest	11.37	0.40
16	Beech forest	23.26	0.83
17	Beech/maple forest	214.87	7.63
18	Beech/other forest	56.82	2.02
19	“Other” forest	0.00	0.00
20	“Other”/maple	102.52	3.64
21	Spruce/fir forest	19.29	0.68
22	Hemlock/pine forest	101.02	3.59
24	Spruce/fir/deciduous forest	24.23	0.86
25	Hemlock/pine/deciduous forest	298.31	10.59

Broad patterns of tree species dominance are evident in the Catskills map (Figure 3.1), but a detailed discussion is probably not appropriate here. In general, maple species dominate broadly over much of the Catskills Park. Oak species occupy significant areas in the eastern portion of the area and beech types are prevalent in the south-central portion of the park west of Slide Mountain. Evergreens occur in scattered patches throughout the Catskills, particularly along riparian corridors and at high elevations.

3.2 Map Accuracy Assessment

The Catskills map included with this report was compared to site data gathered on the ground in the Catskills to characterize map strengths and weaknesses. We present results of both “traditional” map accuracy assessment and “fuzzy” accuracy assessment (see Section 2.5 above) but suggest that the fuzzy assessment is more meaningful in the context of Catskills’ vegetation. Fuzzy assessment offers the opportunity to recognize that, for example, an area occupied by spruce/fir and mapped as pine forest is a less serious error than the same spruce/fir mapped as oak forest. For this report, we include a contingency table summarizing the traditional approach (Appendix B), a detailed fuzzy assessment of the map at each validation site (Appendix C), a summary of the fuzzy assessment (Table 3.2) and a brief discussion of both approaches. Map users are advised to spend considerable time studying the tables to better understand the nature of map errors. Of particular importance are the off-diagonal elements in the traditional contingency table, which represent map errors (mismatches between map and reference data) (Congalton and Green 1993), and the detailed comments in the fuzzy assessment table (Appendix C), which explain the types of confusion found in the map. Users should be cognizant that this assessment is superficial because of the small sample size (Table 2.2) and non-random site locations (Figure 2.3).

3.2.1 Traditional Accuracy Assessment

Appendix B presents four contingency tables (error matrices) summarizing the traditional accuracy assessments of the Catskills map, beginning with the primary vegetation classification with 24 cover types and proceeding to increasingly simplified classifications derived by lumping cover types from the primary classification. Perfect matches between ground data and the vegetation classification are highlighted in orange in the matrix diagonals of the contingency tables. Mismatches (errors) are represented by the off-diagonal elements in the tables. The overall map accuracy indicated above each table expresses the proportion of pixels that are a perfect match between ground data and the vegetation classification. Within each contingency table, two measures of per-type accuracy, called producer’s accuracy and user’s accuracy, are presented (Appendix B). Producer’s accuracy, in the rightmost column, expresses the proportion of pixels for which a vegetation type on the ground is mapped as that type under the “perfect match” criterion. In other words, producer’s accuracy is the proportion of the time that a person standing in an oak forest in the Catskills would find oak for that site on the map. User’s accuracy, in contrast, is the proportion of sites on the map that are the same type on the ground. Although these sound similar, they express different aspects of map accuracy (see Congalton and Green 1993 for a detailed discussion).

In the contingency table for the full 24-class vegetation classification, two types of mismatches are highlighted (Appendix B). In the stippled rectangles, the match is not perfect but species dominance is mapped correctly. This includes, for example, maple-dominated forest with a strong beech component that was mapped as maple-dominated forest with a strong birch component. The two crosshatched areas indicate a different type of mismatch, in which there is confusion between maple vs. beech-dominated forest (unfortunately these forest types have important biogeochemical cycling properties). Careful study of the error matrix in general and of the off-diagonal elements in particular is crucial for understanding map accuracy.

The overall map accuracy is 28% for the classification with all 24 classes, 47% when types are lumped by dominant genus into 7 classes, 84% when the only deciduous classes are oak and non-oak for a total of 4 classes, and 90% when there are just 3 classes (deciduous, evergreen, and mixed) (Appendix B).

It is important to note that many of the types in the map classification (e.g., non-forest) had no validation sites associated with them. These types are indicated by no data (ND) in the contingency table (Appendix B) and their mapped accuracy cannot be determined. Many other types have small sample sizes and our confidence in the accuracy estimates is consequently low. Substantial additional field sampling would be required to improve these estimates.

3.2.2 Fuzzy Accuracy Assessment

Fuzzy accuracy assessment is based on the notion that a binary criterion for map accuracy (right vs. wrong) ignores the fact that some types of map confusion are more serious than others (Gopal and Woodcock 1994). Degrees of error can be quantified by assigning values to a verbal scale (Table 2.5) and using these values to generate descriptions of map accuracy. We present (Table 3.2) the results of a fuzzy assessment using a descriptor called the "RIGHT operator" developed by Gopal and Woodcock (1994). This measure counts a mapped pixel as correct if it is considered a "reasonable or acceptable answer" or better for the site as it is described in the lumped ground validation data (Appendix A). To assign scores from Table 2.5 to mapped pixels at each validation site, we compared the mapped type to the distribution of basal areas by species for that site and summarized these comparisons (Appendix C).

Several points from this analysis deserve emphasis. First, accuracies calculated using the fuzzy "RIGHT" criterion are significantly higher than accuracies based on a binary "right/wrong" criterion. This, of course, is expected since the fuzzy criterion allows a pixel to be counted correct even when the match is not perfect. This expresses a more realistic assessment of the map and, in a sense, quantifies important aspects of the off-diagonal elements in the traditional contingency table (Appendix B) that were described in section 3.2.1 above. Secondly, overall map accuracy using this criterion is about 71%. While this is comparable to other remotely sensed maps in Eastern deciduous forests (e.g., Mickelson, Jr. et al. 1998), it might be improved with other sensors or more intensive ground surveys (see Section 4.0 below). Third, even by this criterion, beech and maple confusion are evident and represent the most significant confusion in the map (Table 3.2). Finally, map user's are encouraged to carefully examine the site-by-site comparison of mapped pixels to ground data included as Appendix C. Study of these comparisons is the most effective way to understand map strengths and weaknesses.

As for the traditional accuracy assessment, the fuzzy assessment suffers from a lack of validation data for some types (“ND” in Table 3.2). The same *caveats* presented for the traditional assessment should be considered when interpreting the fuzzy assessment.

Table 3.2. Fuzzy accuracy summarized for individual mapped cover types and overall fuzzy accuracy for the Catskills land cover map. The percent correct for each mapped cover type is the proportion of validation sites for which the comparison of mapped type to validation site yielded a score of 3 or greater on the verbal scale presented in Table 2.5. Overall fuzzy accuracy is the total number of scores greater than 3 divided by the total number of validation sites (114). ND is No Data—mapped cover type has no validation sites.

Map Code	**Cover Type**	**Percent Correct**
1	Water	ND
2	Non-forest	ND
3	Human built up	ND
4	Oak/laurel forest	83.33
5	Oak forest	ND
6	Oak/maple forest	0
7	Oak/beech or birch or “other” forest	0
8	Maple forest	88.89
9	Maple/oak forest	0
10	Maple/birch forest	71.43
11	Maple/beech forest	33.33
12	Maple/birch/beech forest	66.66
13	Maple/other forest	ND
14	Birch forest	73.68
15	Birch/maple or beech or “other” forest	0
16	Beech forest	0
17	Beech/maple forest	68.18
18	Beech/other forest	33.33
19	“Other” forest	ND
20	“Other”/maple	66.66
21	Spruce/fir forest	85.71
22	Hemlock/pine forest	100.00
24	Spruce/fir deciduous forest	0
25	Hemlock/pine deciduous forest	93.33
	Overall Fuzzy Accuracy	71.05

4.0 Recommendations

4.1 Spectral Limitations

Observed spectral differences between target tree species in the Catskills were subtle in terms of the limited spectral resolution of the TM instrument. These differences vary over time due to differences in timing of phenological change across species and elevation ranges, a circumstance that was exploited using multi-temporal data for this study. Even so, we were often frustrated by very small distinctions in spectral response combined with difficulties untangling species mixtures within TM pixels (see Section 4.2 below). Remotely sensed data offering higher spectral resolution than the TM, in our opinion, would be the most likely way to improve the current map. Higher spectral resolution would require either acquisition of new data from instruments like the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) or the recently launched Hyperion satellite-borne hyperspectral instrument, or, more data acquisitions across time to capture a better sample of phenological change. AVIRIS provides data in 210 narrow (10 nm) spectral bands, offering the possibility of exploiting subtle differences in reflectance between species and of pixel unmixing (see Section 4.2 below). AVIRIS data may be available for the Catskills presently (Lovett, personal communication). The Hyperion satellite collects data in 220 bands, with similar advantages to AVIRIS.

The second recommendation above, acquisition of data to better capture temporal differences in phenology, seems promising. Based on our limited accuracy assessment, the current TM-based classification using only four scene dates captured a reasonable portion of the species variability across the region. Presumably a more carefully orchestrated scene acquisition, coupled with same-time field observation might be an efficient way to improve the map. Special attention to elevational lags in phenology would be an important component of such an effort.

4.2 Spatial Resolution

The spatial resolution of the Landsat TM is 30 meters, meaning that the radiance originating from land cover within each 30 x 30 m area on the ground is averaged to a single digital number (DN) for each of 6 spectral bands. Catskills vegetation, as described by field data collected for this study and by other researchers (e.g., McIntosh and Hurley 1964, McIntosh 1972) is often mixed at this resolution, with various target tree species intermingled within the same “pixel.” This problem, especially in the context of similar spectral characteristics of target tree species, adds to the difficulty of adequately separating and mapping the distribution of dominant species.

Map error resulting from confusion due to mixing within TM pixels might be improved in future efforts using two primary approaches. First, sensors offering higher spatial resolution are currently available and in some cases also offer sufficient spectral and temporal resolution (return time) to be promising. Second, data manipulation known as “pixel unmixing” may allow solving of within-pixel confusion.

Sensors and sensing methods that satisfy the first approach include the IKONOS instrument flown privately by Space Imaging, Inc. (Thornton, CO). This sensor provides 4 m multi-spectral and 1 m panchromatic data and frequent return times. Disadvantages arise from difficulty scheduling data capture and high cost (~\$100 / mile^2). In an area as large as the Catskills, this cost is probably prohibitive. Airborne videography offers another alternative and has been used successfully in the northeastern U.S. to map deciduous tree species (Slaymaker et al. 1996). This technique uses digital video cameras aboard aircraft to capture data. Computer algorithms have been developed to allow data to be georeferenced to ground control points and viewed in stereo. Cost of airborne video is relatively low, but interpretation of the video is laborious and expensive.

The second approach, "pixel unmixing," is limited by the number of spectral bands available, with the total number of within-pixel components (called "endmembers") limited to the number of satellite bands minus 1. For the TM, this means that only 5 endmembers are discernible, a result that is insufficient for capturing the species of interest in the Catskills. Hyperspectral instruments, such as AVIRIS or Hyperion (described above) are better suited to these methods and may be an excellent choice for future work if data are available.

4.3 Ground Data

Ground-based data are critical to the quality of any remotely sensed product, and the Catskills landcover map is no exception. While ground data for the project described in this report were of high quality, they were lacking in quantity and randomness, a situation we discussed in the context of accuracy assessment above. These compromises were a necessary consequence of limited time and resources for ground sampling. Future mapping efforts would benefit from a more extensive program of ground sampling, which, of course, would require significant commitment of resources. In particular, a stratified random sampling regime spanning the full range of vegetation types and elevation ranges would add significantly to the statistical validity of the accuracy assessment. Future mapping efforts would also require additional sampling for training data depending on the sensors used and the timing of satellite data acquisitions. Training data coinciding with the satellite acquisitions would be especially useful.

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Appendix A. Validation sites used for the accuracy assessment of the Catskills vegetation map. The left hand column contains the site number that corresponds to site numbers in Appendix C. Each species is associated with the percent of the total tree basal area at that site. Species are lumped by genus.

1	maple 69.09 birch 30.91
2	maple 41.66 birch 31.67 other 15.0 (hemlock)
3	maple 68.75 other 20.32 birch 6.25
4	maple 51.35 beech 20.27 other 17.57 birch 10.81
5	birch 54.17 beech 20.83 maple 14.58 other 8.34 (hemlock)
6	birch 36.84 maple 36.84 beech 21.05 other 5.26
7	birch 43.48 maple 24.64 hemlock 15.94 beech 14.49 other 1.45
8	birch 60.66 beech 24.59 maple 11.48 other 3.28
9	birch 36.84 maple 29.82 beech 19.3 hemlock 14.04
11	maple 59.26 beech 20.37 birch 16.67 other 3.7
15	maple 41.38 birch 39.66 beech 18.97
16	beech 52.27 birch 31.82 maple 11.36 (hemlock and fir)
17	maple 39.22 birch 37.25 beech 19.61 (fir)
18	beech 46.94 birch 26.53 maple 26.53
21	fir 35.48 birch 27.42 maple 22.58 beech 8.06 other 6.45
22	birch 28.26 maple 28.27 beech 17.39 other 17.39 fir 8.7
24	beech 42.86 other 26.53 birch 16.33 fir 12.24 (maple)
25	other 30.43 beech 23.91 maple 26.09 birch 19.56
26	other 60.38 birch 15.1 beech 13.21 (maple, spruce)
27	maple 29.79 birch 25.53 other 23.4 hemlock 8.51 spruce 8.51
28	birch 40.91 hemlock 20.45 spruce 18.18 maple 15.9 other 2.27 (oak)
30	maple 70.49 other 22.95 (beech, oak)
32	maple 75.41 other 19.68 (oak)
33	maple 53.53 beech 22.39 other 19.41 birch (1.49) (oak)
34	other 47.68 maple 33.72 beech 17.44 (hemlock)
35	beech 43.64 maple 38.18 other 14.54 (hemlock, oak)
36	other 41.1 maple 35.62 beech 23.29
37	maple 34.69 hemlock 28.57 beech 24.49 (other, oak)
38	beech 33.87 other 32.26 maple 29.04 (oak, hemlock)
41	maple 48.0 oak 16.0 hemlock 14.0 beech 10 birch 10 other 2
43	birch 52.38 spruce 25.4 other 9.51 maple 7.93 (oak)
44	spruce 57.14 oak 14.29 maple 10 birch 7.14 other 10 (fir)
45	other 53.33 birch 31.11 maple 8.89 fir 6.67
46	birch 78.26 fir 13.04 other 8.7
47	other 53.85 birch 44.23 (beech)
48	birch 65.91 other 22.73 fir 6.82 maple 4.55
49	other 33.33 maple 29.33 beech 18.67 birch 18.67
50	maple 60 other 31.25 oak 6.25 birch 2.5
51	birch 54.72 maple 28.3 beech 16.98
52	maple 75.81 birch 16.13 beech 4.84 other 3.22
54	maple 65.52 beech 20.69 birch 10.34 other 3.44
55	beech 41.67 birch 30.56 maple 13.89 hemlock 13.89
59	maple 52.31 birch 27.69 beech 13.85 (hemlock)
60	hemlock 53.85 maple 33.33 birch 6.41 beech 5.13 other 1.28
61	maple 39.62 beech 24.53 other 13.21 birch 11.32 hemlock 11.32
62	other 37.14 maple 28.57 beech 18.57 larch 12.86 birch 2.86
63	larch 53.97 maple 36.51 other 9.52
64	spruce 63.53 maple 21.18 other 11.76 (hemlock) birch 1.18
65	oak 61.37 pine 27.27 (maple, other)

66	oak 42.31 maple 26.92 pine 23.08 birch 7.69
67	oak 39.29 maple 28.57 pine 28.57 (beech)
68	oak 86.85 (other, maple)
69	oak 77.15 maple 11.43 birch 8.57 (pine)
70	pine/cedar 32.25 other 29.08 oak 22.58 maple 16.13
71	oak 40 hemlock 35.56 maple 17.78 other 6.66
72	hemlock 42.5 oak 22.5 maple 17.5 other 12.5 birch 3.75 (pine)
73	maple 79.17 birch 14.58 (beech) other 2.08
74	other 48.27 maple 34.49 birch 10.34
75	hemlock 38.81 maple 25.37 pine 22.39 (oak, other)
76	pine 38.46 maple 30.77 birch 10.26 oak 10.26 other 7.69
77	oak 63.48 maple 27.21 (birch, hemlock)
78	oak 40.91 maple 31.82 birch 27.27
79	oak 75.86 maple 13.79 pine 10.34
80	oak 89.48 (maple, pine)
81	hemlock 42.86 maple 22.86 birch 17.14 other 15.72 (beech)
83	maple 38.71 oak 14.52 beech 12.9 other 12.9 hemlock 11.29 birch 9.67
84	hemlock 53.85 other 24.62 maple 15.38 birch 4.62 (pine)
85	maple 41.07 beech 32.14 hemlock 10.71 other 8.93 birch 5.36 (pine)
86	birch 38.64 maple 38.63 hemlock 11.36 other 6.82 (beech)
89	hemlock 74.6 maple 11.11 pine 4.76 oak 4.76 (beech, other)
90	pine 47.62 other 19.05 maple 16.67 hemlock 14.29
91	maple 51.06 birch 36.17 other 6.39 beech 4.26 (pine)
92	beech 43.24 birch 32.43 maple 24.32
93	beech 100
94	hemlock 61.67 maple 15 birch 13.34 (pine, oak, beech, other)
95	hemlock 52.94 maple 26.47 birch 11.76 (pine, oak, beech, other)
96	pine 60.19 maple 15.47 birch 12.81 other 8.96
97	oak 33.33 other 30 pine 13.33 birch 10 maple 10
98	other 40.63 beech 28.13 birch 17.19 maple 14.06
99	birch 73.53 other 17.65 maple 8.82
101	other 46.51 birch 27.91 maple 13.95 beech 11.63
102	other 62.69 maple 16.42 birch 8.96 beech 7.46 (hemlock, spruce, fir)
103	other 63.46 maple 26.92 (beech, birch 3.85)
104	birch 55.1 other 20.41 beech 14.29 maple 10.2
105	beech 40.43 birch 27.66 maple 21.28 other 10.64
107	maple 42 beech 40 other 12 birch 6
110	beech 38.78 maple 28.57 birch 28.57 other 2.04 (hemlock)
111	other 40.3 beech 34.33 maple 25.37
112	fir 95 (other)
113	fir 85 (other)
114	fir 82 (other)
115	fir 84 (other)
116	for 75 (other)
117	hemlock 40 maple 31 (beech, other)
118	oak 76 maple 14.66 birch 6.66 other 2.67
119	maple 62.26 beech 22.64 birch 13.21 other 1.89
120	other 34.55 maple 23.64 beech 23.64 birch 16.36 (hemlock)
121	maple 55.36 beech 26.79 birch 10.71 other 7.14
123	beech 47.17 maple 20.76 other 20.75 birch 9.43 (hemlock)
125	other 36.84 beech 24.56 maple 22.8 birch 15.79
126	birch 66.67 beech 22.22 maple 11.11
127	birch 24.19 maple 20.97 other 17.74 beech 16.13 oak 16.13
128	oak 71.05 maple 11.84 (birch, other, hemlock, pine)
129	beech 41.79 oak 22.39 maple 22.39 birch 13.43
130	oak 51.92 maple 19.23 birch 19.23 other 1.92
131	oak 92.75 (maple, birch)

132 other 51.56 beech 25 maple 18.75 (birch)
133 maple 53.57 birch 14.29 beech 12.5 other 10.72 hemlock 8.93
134 beech 48.48 maple 30.3 birch 12.12 other 4.55 (hemlock)
135 beech 47.06 birch 26.47 maple 26.47
136 maple 46.16 beech 36.92 birch 13.85 (hemlock)
137 other 36 maple 34.67 beech 28 birch 1.33
138 hemlock 34.33 maple 26.86 birch 23.88 beech 11.94 other 2.99
139 hemlock 77.38 birch 15.48 (maple)

Appendix B**.**

1) Accuracy assessment of vegetation classification with 24 classes
Perfect matches are highlighted in orange, stippled areas are pixels for which dominant genus is correct, and crosshatched areas highlight confusion between maple and beech types. Producer's accuracy is on the right and user's accuracy is shown across the bottom of the matrix. "ND" signifies types for which there were no validation data. Overall, 28% of the reference(ground) vs. mapped vegetation comparisons are perfect matches using this classification.

Reference Type	Mapped Type																									Producer's Accuracy
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	24	25	TOTAL	
Water (1)																									0	ND
Non-forest (2)																									0	ND
Human built-up (3)																									0	ND
Oak/laurel (4)																									0	ND
Oak forest (5)				7										2											9	0.00
Oak/maple forest (6)				2																					2	0.00
Oak/beech,birch or other (7)				1								1						1							3	0.00
Maple forest (8)								5		1															6	0.83
Maple/oak forest (9)							1										1								2	0.00
Maple/birch forest (10)								1	1	2															4	0.50
Maple/beech forest (11)				1											1	1	5								8	0.00
Maple/birch/beech forest (12)														1			1						1		3	0.00
Maple/other forest (13)											2						3				1				6	0.00
Birch forest (14)												1		3											4	0.75
Birch/maple, beech, other (15)								1		1		2		3			1	1							9	0.00
Beech forest (16)											1														1	0.00
Beech/maple forest (17)														1			3							1	5	0.60
Beech/other forest (18)									1	2				4			2								9	0.00
Other forest (19)						1						2		2			4	1		1					11	0.00
Other/maple forest (20)										1				1			2			1					5	0.20
Spruce/fir forest (21)																				1	5				6	0.83
Hemlock/pine forest (22)																					1			1	2	0.00
Spruce/fir/decid forest (24)														1								1		1	3	0.00
Hemlock/pine/decid forest (25)				1				2						1										12	16	0.75
TOTAL	0	0	0	12	0	1	1	9	2	7	3	6	0	19	1	1	22	3	0	3	7	1	1	15	114	
User's Accuracy	ND	ND	ND	0	ND	0	0	0.6	0	0.3	0	0	ND	0.2	0	0	0.1	0	ND	0.3	0.7	0	ND	0.8		

2) Accuracy assessment of vegetation classification with 7 classes (lumped by dominant genus)
Overall, 47% of the reference(ground) vs. mapped vegetation comparisons are perfect matches using this classification.

Reference Type	Mapped Type								Producer's
	4-7	8-13,20	14-15	16-18	19	21-22	24-25	TOTAL	Accuracy
Oak (4-7)	10	1	2	1				14	0.71
Maple (8-13,20)	2	14	3	13		1	1	34	0.41
Birch (14-15)		5	6	2				13	0.46
Beech (16-18)		4	5	5			1	15	0.33
Other Decid (19)	1	3	2	5				11	0.00
Evergreen (21-22)		1				6	1	8	0.75
Ever/Decid mix (24-25)	1	2	2			1	13	19	0.68
TOTAL	14	30	20	26	0	8	16	114	
User's Accuracy	0.71	0.47	0.30	0.19	ND	0.75	0.81		

3) Accuracy assessment of vegetation classification with 4 classes
Overall, 84% of the reference(ground) vs. mapped vegetation comparisons are perfect matches using this classification.

Reference Type	Mapped Type					Producer's
	4-7	8-20	21-22	24-25	TOTAL	Accuracy
Oak (4-7)	10	4			14	0.71
Other Decid (8-20)	3	67	1	2	73	0.92
Evergreen (21-22)		1	6	1	8	0.75
Ever/Decid mix (24-25)	1	4	1	13	19	0.68
TOTAL	14	76	8	16	114	
User's Accuracy	0.71	0.88	0.75	0.81		

4) Accuracy assessment of vegetation classification with 3 classes
Overall, 90% of the reference(ground) vs. mapped vegetation comparisons are perfect matches using this classification.

Reference Type	Mapped Type				Producer's
	4-20	21-22	24-25	TOTAL	Accuracy
Decid (4-20)	84	1	2	87	0.97
Evergreen (21-22)	1	6	1	8	0.75
Ever/Dec mix (24-25)	5	1	13	19	0.68
TOTAL	90	8	16	114	
User's Accuracy	0.93	0.75	0.81		

Appendix C. Comparison of mapped cover types to validation data gathered on the ground in the Catskills. Ground site ID is from IES data. Validation ID corresponds to the user-ID in the arc/info coverage of ground points ("validation" on CD). Mapped and reference types correspond to the codes listed in Table 2.3 of the report. The fuzzy assessment is the rating for comparison of each ground site to the mapped pixel at that site according to the following scale: 1 = absolutely wrong, 2 = wrong but understandable, 3 = reasonable answer, 4 = good answer, 5 = absolutely correct (Table 2.5 in report) (Gopal and Woodcock 1994).

Ground Site ID	Validation ID	Mapped Type	Reference (Ground) Type	Fuzzy Assessment	Comments
BB1	1	8	8	5	Perfect match.
BB2	2	10	10	5	Perfect match.
BB3	3	8	8	5	Perfect match.
BB4	4	17	11	3	Mapped beech/maple. Should be maple/beech.
BB5	5	10	15	2	Mapped as maple/birch, both of which are present, but birch is strongly dominant.
BB6	6	17	15	3	Mapped beech/maple. Site is mixture of "other," maple and beech.
BB7	7	14	15	4	Mapped pure birch. Site is birch dominated with maple.
BB8	8	12	15	3	Mapped maple/birch/beech. Site is birch/beech/maple.
BB9	9	14	15	4	Mapped pure birch. Site is birch dominated with maple.
BB11	11	17	11	3	Mapped beech/maple. Should be maple/beech.
BB15	15	14	12	3	Mapped pure birch. Should be maple dominated with birch.
BB16	16	10	18	2	Mapped maple/birch. Site is beech with birch and maple.
BB17	17	24	12	1	Mapped spruce/fir/decid. Site is deciduous with very minor evergreen component.
BB18	18	17	17	5	Perfect match.
BB21	21	14	24	3	Mapped birch. Site is fir with birch.
BB22	22	18	15	2	Mapped beech/other. Site is mixture of birch, maple, beech and "other."
BB24	24	14	18	3	Mapped birch. Site is beech dominated with other and birch.
BK1	25	20	20	5	Perfect match.
BK2	26	20	19	4	Mapped other/maple. Site is dominated by "other" but has little maple.
BK3	27	21	13	2	Mapped spruce/fir. Site has some evergreen, but is deciduous dominated.

Ground Site ID	Validation ID	Mapped Type	Reference (Ground) Type	Fuzzy Assessment	Comments
BK4	28	14	25-24	3	Mapped birch. Site is birch dominated but with significant hemlock and spruce.
BK6	30	17	13	2	Mapped beech/maple. Site is maple dominated with very little beech.
BK8	32	8	8	5	Perfect match.
BK9	33	17	11	3	Mapped beech/maple. Site is maple beech.
BK10	34	17	20	2	Mapped beech/maple. Site is dominated by “other” with maple and beech.
BK11	35	17	17	5	Perfect match.
BK12	36	17	13	2	Mapped beech/maple. Site is dominated by “other” with significant maple and beech.
BK13	37	25	25	5	Perfect match.
BK14	38	17	18	4	Mapped beech/maple. Site is beech dominated with lots of “other” and maple.
BK17	41	17	9	2	Mapped beech/maple. Site is strongly dominated by maple.
BK19	43	25	24	4	Mapped hemlock/pine/decid. Site is birch dominated with spruce.
BK20	44	22	24	3	Mapped hemlock/pine. Site is spruce dominated with significant deciduous.
RH1	45	17	19	1	Mapped beech/maple. Site is dominated by “other” species.
RH2	46	14	14	5	Perfect match.
RH3	47	14	19	4	Mapped birch. Site is dominated by “other” species with lots of birch.
RH4	48	14	14	5	Perfect match.
RH5	49	17	20	2	Mapped beech/maple. Site is dominated by “other” with maple and beech.
RH6	50	17	13	1	Mapped beech/maple. Site is strongly maple dominated.
RH7	51	14	15	4	Mapped birch. Site is dominated by birch with lots of maple.
RH8	52	8	8	5	Perfect match.
RH10	54	10	8	4	Mapped maple/birch. Site is maple dominated with very little birch.
RH11	55	14	18	3	Mapped birch. Site is

Ground Site ID	Validation ID	Mapped Type	Reference (Ground) Type	Fuzzy Assessment	Comments
					beech dominated with significant birch.
RH15	59	10	10	5	Perfect match.
RH16	60	8	25	2	Mapped maple. Site is hemlock dominated with lots of maple.
RH17	61	15	11	2	Mapped birch/maple or beech. Site is maple dominated with beech and birch.
RH18	62	11	13	3	Mapped maple/beech. Site is dominated by "other" species with lots of maple and beech.
RH19	63	8	25	3	Mapped maple. Site is larch dominated with maple.
RH20	64	21	21	5	Perfect match.
0514A	65	4	5	5	Perfect match. (Pure oak)
0514B	66	4	6	4	Mapped oak. Site is oak dominated with maple and pine.
0514C	67	4	7	4	Mapped oak. Site is oak dominated with maple and pine.
0514D	68	4	5	5	Perfect match. (Pure oak)
0514E	69	4	5	5	Perfect match. (Pure oak)
0582	70	6	19	2	Mapped oak/maple. Site is pine/cedar with lots of other, oak and maple.
0624A	71	25	25	5	Perfect match.
0624B	72	25	25	5	Perfect match.
0634A	73	8	8	5	Perfect match.
0634B	74	11	13	2	Mapped maple/beech. Site dominated by "other" species with significant maple.
0730	75	25	25	5	Perfect match.
0772A	76	4	25	1	Mapped oak. Site dominated by pine with only small amount of oak.
0772B	77	4	5	5	Perfect match. (Pure oak)
0772C	78	4	6	4	Mapped oak. Site dominated by oak but with lots of maple and birch.
0772D	79	4	5	5	Perfect match. (Pure oak)
0772E	80	4	5	5	Perfect match. (Pure oak)
0840A	81	25	25	5	Perfect match.
0840C	83	7	9	2	Mapped oak/beech or birch. Site dominated by maple with some oak and beech.
0907A	84	25	25	5	Perfect match.
0907B	85	4	11	1	Mapped oak. Site is

Ground Site ID	Validation ID	Mapped Type	Reference (Ground) Type	Fuzzy Assessment	Comments
					maple/beech.
0907C	86	9	10	2	Mapped maple/oak. Site is birch dominated with maple.
1094A	89	25	22	4	Mapped hemlock/pine/decid. Site is strongly dominated by hemlock with only minor deciduous species.
1094B	90	25	25	5	Perfect match.
1241A	91	8	10	4	Mapped maple. Site is maple dominated with lots of birch.
1241B	92	9	18	1	Mapped maple/oak. Site is beech dominated with birch and maple.
1241C	93	11	16	2	Mapped maple/beech. Site is pure beech.
1782A	94	25	25	5	Perfect match.
1782B	95	25	25	5	Perfect match.
2037A	96	25	25	5	Perfect match.
2037B	97	12	7	1	Mapped maple/birch/beech. Site is oak/”other”.
GP7	98	12	19	3	Mapped maple/birch/beech. Site is mix of other, beech, birch and maple.
GP8	99	12	14	2	Mapped maple/birch/beech. Site strongly birch dominated.
GP10	101	14	19	4	Mapped birch. Site is “other” dominated with lots of birch.
GP11	102	14	20	3	Mapped birch. Site is “other” dominated with maple and birch.
GP12	103	10	20	3	Mapped maple/birch. Site is “other” dominated with maple.
GP13	104	12	15	3	Mapped maple/birch/beech. Site is mix of birch/other/beech/maple.
GP14	105	14	18	2	Mapped birch. Site is beech dominated with significant birch.
GP16	107	25	17	1	Mapped hemlock/pine/decid. mix. Site has no evergreen.
GP19	110	10	18	3	Mapped maple/birch. Site is beech dominated with lots of maple and birch.
GP20	111	17	19	3	Mapped beech/maple. Site is “other” dominated with lots of beech and maple.
GP2	112	21	21	5	Perfect match.
GP3	113	21	21	5	Perfect match.

Ground Site ID	Validation ID	Mapped Type	Reference (Ground) Type	Fuzzy Assessment	Comments
GP4	114	21	21	5	Perfect match.
GP5	115	21	21	5	Perfect match.
GP6	116	20	21	1	Mapped "other"/maple. Site is fir dominated.
10	117	21	22	4	Mapped spruce/fir forest. Site is hemlock.
13	118	4	5	5	Perfect match (pure oak).
16	119	17	11	3	Mapped beech/maple. Site is maple/beech.
18	120	12	19	3	Mapped maple/birch/beech. Site is mix of other/maple/beech/birch.
19	121	16	11	2	Mapped beech. Site is maple dominated with beech.
21	123	17	17	5	Perfect match.
31	125	17	19	3	Mapped beech/maple. Site is dominated by "other" with significant beech and maple.
35	126	14	14	5	Perfect match.
40	127	8	15	3	Mapped maple. Site is birch dominated with significant maple.
42	128	14	5	1	Mapped birch. Site is oak.
46	129	14	18	2	Mapped birch. Site is beech dominated with some birch.
47	130	18	7	2	Mapped beech/other. Site is oak/beech.
48	131	14	5	1	Mapped birch. Site is oak.
66	132	17	19	3	Mapped beech/maple. Site is dominated by other with significant beech and maple.
69	133	17	12	3	Mapped beech/maple. Site is mixture of maple, birch and beech.
70	134	14	17	2	Mapped birch. Site is beech dominated with maple.
71	135	17	18	3	Mapped beech/maple. Site is beech dominated with significant maple and birch.
73	136	17	11	3	Mapped beech/maple. Site is maple/beech.
74	137	18	19	3	Mapped beech/other. Site is "other" dominated with maple and beech.
77	138	25	25	5	Perfect match.
89	139	25	25	5	Perfect match.